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RECENT USSR LITERATURE ON CONTROL OF PARTICULATE EMISSIONS FROM STATIONARY SOURCES

by

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ABSTRACT

About 600 articles published from about 1970 through 1975 in several technical and scientific journals in the U.S.S.R. were compiled and classified according to subject content. These articles were selected as indicators of U.S.S.R. technology in controlling air pollution by particulate emissions from stationary sources, with special emphasis on fly ash from the combustion of coal in electric power plants. The control devices include electrostatic precipitators, wet scrubbers, fabric filters, cyclones, and granular bed filters.

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16. ABSTRACT: The report reviews approximately 600 articles, published between 1970 and 1975 in several technical and scientific journals in the USSR and compiled and classified according to subject content. The articles were selected as significant indicators of the status of the technology of controlling air pollution by particulate emissions from stationary sources, with emphasis on fly ash from the combustion of coal in electric power plants. Control devices include electrostatic precipitators, wet scrubbers, fabric filters, cyclones, and granular bed filters.

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Dust		Stationary Sources	11G	
Fly Ash	Scrubbers	Particulate	21B	07A
Coal	Granular Materials	USSR	21D	
Combustion	Fabrics	Wet Scrubbers		11E
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Cyclone Separators		Granular Bed Filters		

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SECTION 1

INTRODUCTION

The scope of this literature survey is the technical and scientific information recently published in the U.S.S.R. that is significant in showing the status of the technology of controlling particulate emissions from stationary sources, with special emphasis on fly ash from the combustion of coal in electric power plants. The survey is intended to include the essential information, but not to provide complete bibliographic coverage of the subject.

The scope was operationally defined in terms of manual searching of indexes for pertinent items, in Chemical Abstracts (1973-1975), Air Pollution Abstracts (1973-1975), Engineering Index (1973-1975), Physics Abstracts (1973-1975), Electrical and Electronics Abstracts (1973-1975), and Referativnyi Zhurnal Khimiya (1975-1976, Nos. 1-6). Some pertinent items that had been obtained from these sources in 1970 through 1972 were also included.

The following publications were covered by searching their title pages for 1973-1975 in Current Contents - Physical and Chemical Sciences and Current Contents - Engineering, Technology and Applied Sciences: Khimicheskaya Promyshlennost' (Soviet Chemical Industry), Stal' (Steel in the USSR), Zhurnal Prikladnoi Khimii (Journal of Applied Chemistry of the USSR), and Zhurnal Tekhnicheskoi Fiziki (Soviet Physics-Technical Physics).

Each issue of the following journals for 1973-1975 was examined: Elektricheskiye Stantsii [electric power plants], Elektrichestvo (Electric Technology USSR), Energetik [power], and Teploenergetika (Thermal Engineering). The names in parentheses are those of translations that are available.

Some items from APTIC searches that had been made on the subjects of particulate control and measurements were included in the survey.

The search also included a number of unpublished reports that were provided by the U.S.S.R. members to the U.S. members of the Stationary Source Air Pollution Control Technology Committee and the Committee on Design and Operation of Air Pollution Reduction and Waste Disposal Systems for Thermal Power Plants.

Other articles, titles, and abstracts were provided by the staff of the Environmental Protection Agency Industrial Environmental Research Laboratory.

SECTION 2

ELECTROSTATIC PRECIPITATORS

USE IN ELECTRIC POWER PLANTS

Electrostatic precipitators are used in the U.S.S.R. on electric power units of 300 MW and larger, and on plants burning coal with 15% or more ash. Precipitator designs and the theoretical basis for them have been presented (1,2).

To supply the electrical energy needs of the U.S.S.R. requires the use of Baltic shale and coal from the large Ekibastuz and Kansk-Achinsk deposits (3). The shale has a high ash content (50%) with a high lime content (4). Ekibastuz coal has a high ash content (40%), a low sulfur content (<1%), and a high silica content in the ash (typically 65%), and the fly ash has a high electrical resistivity (10^{11}-10^{13} ohm-cm) (4,5). The Kansk-Achinsk fuel is a low-ash low-sulfur lignite. Its ash has a high lime content (6).

When fuels such as Ekibastuz coal began to be used, electrostatic precipitators collecting fly ash gave lower collection efficiencies than the design efficiency of about 99%. It was known that a fly ash with a high electrical resistivity is difficult to collect, and so attempts to improve the collection efficiency began with changes in the design of the precipitator to avoid back corona and sparking through the layer of fly ash deposited on the collection electrode (7). Since electrical breakdown of the fly ash layer is a function of its electrical resistivity and the current density, a more uniform current density would permit operation at a higher resistivity before the onset of back corona.

This approach led to modification of the shape of the corona electrode to achieve a more uniform electric field and current density. The U.S.S.R. precipitator design, like the German Lurgi design, has a frame-supported corona electrode assembly. The corona electrode is a strip of metal approximately 1.4 mm thick and 25 mm wide. Equipping the electrode with needle-like protrusions was found to improve the performance of the precipitator (8,9).

Studies of the distribution of corona current and of the volt-ampere characteristic of the needle-shaped electrodes led to the conclusion that they allow the collection of high-resistivity dusts with decreased likelihood of back corona and with increased collection efficiency (10).

Further, when the orientation of the needles on a corona electrode was changed from the normal perpendicular configuration to one parallel to the collection electrodes, a larger difference in potential between the corona and the collection electrode was found. The discharge from each needle is directed to both collection electrodes, the field near the collection electrode is equalized, and the effectiveness of cleaning the gas is increased, especially in collecting high-resistivity ash. This method of intensifying the discharge and collecting fly ash has found wide application both in operating and newly constructed electric power plants (11,12).

Modification of the corona system in electrostatic precipitators on 300 MW units in a power plant by installing leaf-needle electrodes with a distance between the needles of 40 mm and rotation of the elements to orient the needles in the direction of gas flow, together with improvements in the rapping regime and the electrification equipment, resulted in an increase of the collection efficiency from 87.5 to 96.8% (13,14).

To determine the optimal construction parameters in an experimental-industrial horizontal electrostatic precipitator at a power plant treating 20,000 m^3/hr, its electrical characteristic was investigated as it related to the length of the needles while retaining a constant discharge distance. It was found that, by changing the length of the needles, the corona current could be regulated over a wide range. A study was also made on a model plate precipitator with an industrial needle electrode system. Orientation of the needles in the direction of the gas flow substantially decreased the specific corona current density (15).

An investigation of electrical wind which was made on bench units showed that an intensive flow arises with a corona discharge from needles; the electrical wind near the needles can attain a velocity of several meters per second. The local flow of the electrical wind is largely swept away by the main gas flow, but owing to the large number of corona points, the electrical wind helps move the fine dust from the central part of the gas passageway toward the collection electrode (11).

However, modification of the electrodes may not completely prevent the appearance of back corona when high-resistivity ash is collected. Therefore, at electric power plants which collect the ash of low-sulfur coals, methods for humidifying

(conditioning) flue gases prior to their entry into the electrostatic precipitators have been developed which permit a reduction in the specific electrical resistance of the ash and an improvement in the discharge characteristics of the gas gap. In such instances, the effective migration velocity of the particles could be increased 1.5- to 2-fold without any change in the design of the electrostatic precipitator, except that the rapping of the collection electrodes was changed to more effective rapping mechanisms (11).

A wet scrubber can be installed ahead of the precipitator to add the moisture. The scrubber also reduces the temperature with a generally beneficial effect on collection. The types of scrubbers that have been used are spray chambers or venturi designs modified by the incorporation of spray nozzles (3).

Basic parameters of a combined ash trapping scheme tested at a 300 MW unit of a power plant firing high-ash coal are presented (15). The facility is composed of a wet venturi for removing 90% of the ash and for cooling the flue gas to 75-80°C. The wet flue gas carrying ash with a reduced electrical resistivity is then admitted into an electrostatic precipitator which has an efficiency of 99-99.5%.

Modifications of electrostatic precipitators collecting fly ash from the combustion of Baltic shale are described. The modifications consist of the installation of needle-shaped corona electrodes and changes in the electric power supply (4,8,16).

The use of electrostatic precipitators in the collection of fly ash with a high lime content (28% CaO) from Irsha-Borodino coal is described (17). The chemical composition of the fly ash from this coal is given (18).

In the collection of fly ash with a high lime content, hydration of calcium oxide in the ash layer on the collection electrodes hardens the deposited layer, which worsens the electrical indexes of the precipitators with time, especially when wire corona electrodes are used. Under these conditions, needle electrodes operate considerably more reliably (11).

Data are presented on horizontal plate-type electrostatic precipitators used in thermal electric power stations and in cement plants (19,20).

Reconstruction of an electrostatic precipitator to replace the corrugated collection electrodes by C-shaped electrodes, use of impact hammer rappers, and use of needle-shaped electrodes improved the performance of the precipitator in collecting fly ash (13).

Similar measures were successfully applied to electrostatic precipitators used for removing fly ash from oil shale combustion (21).

The collection efficiency of horizontal electrostatic precipitators collecting high resistivity fly ash from low-sulfur coal was increased by changing the rapping procedure and decreasing the flue gas temperature from 140° to 122°C (22,23).

Problems encountered in installing an electrostatic precipitator in a 300 MW power block are described (24).

The costs of electrostatic precipitators relative to their sizes have been considered (25,26). The use of a laboratory version of an electrostatic precipitator for developing best conditions for the collection of fly ash from Ekibastuz coal is described (27). Improved methods of calculating efficiency of removal of fly ash in power boilers are given (28).

A series of papers published in 1974 provides details of the history of research and development of control methods for particulate emissions at NIIOGAZ (29-35).

A source book published in 1969 presents background information on the technology of the cleaning of stack gases in the electric power industry in the U.S.S.R. The information includes discussions of various problems related to the design and operation of gas cleaning systems (36), and the determination of the basic properties of dusts and gases (37,38).

A more recent compilation that presents a selection of new published and unpublished information on various air pollution control devices and their applications has been provided (39).

CORONA AND ELECTRICAL BREAKDOWN

Several basic studies have been reported in recent years on corona discharges and associated electrical phenomena in gases. Some of these investigations are related to the processes that take place in electrostatic precipitators; others are less relevant since they pertain to conditions such as low gas pressure or to electrical breakdown in high-voltage conductors.

A comprehensive review and summary of the fundamentals of the electrodynamics of suspended particles was published in 1974. It includes a discussion of techniques that have been developed for characterizing electric fields and for studying the behavior of charged particles in them, specifically the collection of particles from gas streams (40).

The effect of variations in the mobilities of ions in unipolar corona was studied (41). Changes in ion mobility had a slight effect on the overall shape of the volt-ampere characteristic, but produced a marked change in the distribution of the field potential in the corona discharge gap. A dynamic method for determining ion mobility was developed (42).

The effects of dust concentration and the resulting particle space charge on the corona field have been calculated (43,44). Measuring the electric field of a corona discharge in a dust-laden stream is also discussed (45).

The effects of free radicals from the gas on the performance of electrostatic precipitators was shown experimentally. The presence of free radicals can explain the formation of space charges between positive and negative electrodes. The addition of substances tending to form free radicals could aid in gas cleaning (46). A comparison of the effects of surface finishes and treatments of the cathode indicates that positive ions in the gas and on the cathode surface control the production of effective electrons (47).

Electric breakdown of air gaps has been studied under conditions typical of electrostatic precipitation for wire-plane and coaxial cylinder geometries with various shapes of electrodes (48-52). The initiation voltage is calculated (51). The effect of transitional processes in sparkover on precipitator efficiency was studied (54).

Other studies on corona include: the electrical discharge in a multi-electrode system (55); the corona initiation voltage in structures with semi-conducting coatings (56); the erosion of electrodes in point-to-plane discharge (57,58); the determination of corona initiation voltage for electrodes of complex shape (59,60); the efficiencies of electrostatic precipitators with various types and shapes of corona electrodes (61-64).

The electrical characteristic of the electrode system and the trajectories of dust particles were measured under conditions of back corona in an electrostatic precipitator (65).

An experimental study of particle trajectories showed that corona from a needle-shaped electrode improves the electrical characteristic of a precipitator and allows a higher migration velocity of the particles (66).

A laboratory study of a plate electrostatic precipitator with a cylindrical discharge electrode (needle-leaf shape) established the applicability of the precipitator for the calculation of the attenuation of current found in the presence of the dispersed phase in the interelectrode space (67).

The equation of the field in corona discharge in an electrode system consisting of a row of conductors between planes was solved by the use of a series expansion to calculate the field potential. This method gives better agreement with experimental data than the Deutsch-Popkov method. The values calculated for space-charge density by the two methods differ by 10% at the plane, 80% at the midpoint of the distance between conductor and plane, and 40% at the midpoint of the inter-conductor distance (66).

Mathematical models and calculations of the initiation of electrical discharge and breakdown have been developed (69-71).

The distribution of current of unipolar corona at the corona and non-corona electrodes was measured. The results indicated that the distribution of current depended on the intensity of the corona and the electrode geometry, in accordance with theory. The current distribution on the surface of the corona electrode was not uniform (72).

The results of an extensive study on the characteristics of corona discharge in air and in blast-furnace gas indicate that operation of an electrostatic precipitator should be more effective at 4 atm pressure of blast furnace gas than at atmospheric pressure (73,74).

The mobility of hydrogen ions in the field of unipolar corona in a cylindrical electrode geometry at pressures up to 25 atm was determined experimentally (75).

ELECTRIC FIELD

A number of investigations and calculations of electric fields have been carried out. Examples are: a method of linear programming for calculation of fields (76), calculation of the field between point and plane (77), calculation of the field in a spatial system of spherical elements (78), with ring electrodes (79), a system of parallel toroids (80), in a heterogeneous medium of irregular structure (81), and for conducting particles (82); with the use of an integral equation of the first order (83,84), of the second order (85), in a periodic system of interacting spheroids (86), and for a screen with a complex shape (87); and calculation of plane-meridian and plane-parallel fields (88-90).

A method of analysis of 2-dimensional fields formed by electric or magnetic polarisation of solids is presented (91).

An ionisation mechanism of the instability of currents in molecular gases is proposed (92,93).

PARTICLE CHARGING

The field-charging and diffusion-charging mechanisms of particle charging in a corona discharge are discussed from a theoretical point of view (94,95). A distribution curve for particle charges was constructed in a study of the charging of particles with radii of the order of the mean free path of ions in air (96).

The distribution of dust concentration in the fields of an electrostatic precipitator was determined (97). The limit concentrations of the dispersed phase in the electric field of corona discharge resulting from the decrease in free ion concentration with increasing space-charge density were calculated (98). The electric field and an image charge of charged particles near a non-uniform surface were calculated (99).

Calculations were made of the orientation time and velocity of ellipsoidal particles in electric fields of 1-3 and 5-10 kV/cm (100). A study was made of the statistical distribution of the parameters involved in the orientation of elongated particles (fibers) in an electrostatic field (101).

Equations were derived for describing the motion of ions and particles in the field of corona discharge (102). The kinetics of coagulation of charged particles were modelled mathematically (103). Charge transfer in the collision of charged drops was studied experimentally (104).

The charges acquired by aspherical particles in a corona field can usually be calculated with sufficient accuracy by assuming the shape to be an ellipsoid of the same axial ratio and volume. However, up to 10% error can result if the shape of the particle is sufficiently different, and the amount of charge acquired can be limited by the onset of corona from the particle if it is conducting and has a conical shape (105).

The coefficients of coalescence and dispersion of charged particles are functions only of the coefficient of electric asymmetry (106).

Experimental studies on electrostatic liquid atomisers included the effect of electric field on dispersion (107,108), the energy content of the droplets (109), and their charges (110).

The effect of the plate spacing on the electrostatic collection of high-resistivity dust was determined (111).

The relationships of dielectric permeability, time, form, and concentration of the dispersed phase to the frequency of a sinusoidal electric field were studied (112).

The steady state concentrations of electrons during photoionisation of aerosol particles were calculated (113).

A theory of the induction method of measuring the volume charge density of aerosol particles is proposed, and the parameters of the measuring apparatus are discussed (114).

An electrostatic analyser for charged particles (115) and a parallel-plate capacitor as a charged particle spectrometer (116) are discussed.

A patent on the removal of aerosol particles from a gas stream by an electrostatic field with preliminary charging of the particles claims increased efficiency by the use of focusing electrostatic or magnetic lenses (117).

PARTICLE COLLECTION

Results are presented of solutions to equations calculating the migration and charge of particles in an electric field with a space charge and mixing of the suspension in turbulent flow, in the collection of a monodisperse dust in a tubular electrostatic precipitator (118).

In a theoretical study of the orientation of prolate ellipsoidal particles moving in an electric field, the particle orientation time is related to the hydrodynamic moment (119).

A theory is developed for the deposition of unipolarly charged particles in an electrostatic field on grounded and insulated bodies (120,121). Mathematical models of the particle collection process have been derived (122).

Equations were developed for calculating the collection efficiency of an electrostatic precipitator (Deutsch equation), the electrical field at the collection electrode, the effect of the ionic mobility, and the effects of electrical field and current on the collection efficiency (123).

The deposition of dust particles from turbulent gas streams was studied and the extent of error introduced into the calculation of collection efficiency of an electrostatic precipitator by the assumption of uniform mixing of dust in the gas flow was estimated for various conditions (124,125).

The increase in the rate of gas cleaning by proper design of the corona electrode, taking into account the character of the distribution of the dust across the electric field, is discussed (126).

Acoustic pretreatment of gases from open-hearth furnaces and sintering machines increased the collection efficiency of an electrostatic precipitator (127).

Coagulation of bipolarly charged particles in an electric field occurred above a critical value of the field which increased with increasing charge. The use of an electric field for this purpose is of value only for low particle charges (128).

ELECTRICAL RESISTIVITY OF PARTICULATE MATTER

An instrument similar to the Lurgi instrument for measuring the electrical resistivity of dust under industrial conditions was developed. The principle of operation involves measuring the resistance of a dust layer formed in a corona discharge field. The dust is deposited from the gas by the electric field produced by a corona discharge electrode (129,130).

In a second method, a layer of the dust (extracted from the exhaust gas) is formed by pouring it between two flat filter surfaces and then compressing it by a standard load. The use of a filter as an electrode makes it possible to draw gas through the sample (131). A patent describes a similar apparatus in which the electrodes are in the form of cermet filters (132).

Still another method permits in-situ measurement of dust resistivity in flue gas. The dust-laden gas flows into a cyclone from which the deposited dust falls into a hopper that feeds it to a cell equipped with measuring electrodes (133).

Some factors affecting resistivity of dusts are discussed (134).

The dielectric strength of a dust layer depends on the packing coefficient, which in turn depends on the size and shape of the particles. The results of calculating the breakdown gradient of the layer are given in equations. The good agreement with experiment indicates that they can be used to determine the onset of back corona (135).

The potential of an electrostatic precipitator in weakly developing back corona and its dependence on the specific electrical resistivity of the dust was considered (136).

COMPOSITION AND PROPERTIES OF FLY ASH AND OTHER DUSTS

The effects of water-soluble components of cement dust at various temperatures and moisture contents on the specific electrical resistivity were determined (137). Similar effects of temperature and moisture contents of tin metallurgy dusts

were studied (138). The efficiency of an electrostatic precipitator in collecting various metal oxides was determined (139). Chemical and physical properties of dusts from a copper smelter were measured (140). The chemical composition and physical properties of dust from the production of aluminum and the silicon-aluminum alloy silumin were measured (141). Similar properties of dusts occurring in the production of mercury were measured (142).

In the combustion of some lignites and brown coals, the relation of the sintering strength of fly ash to the chemical composition and particle size of the ash has been studied (143).

The shale burned in Baltic electric power stations produces an ash high in lime. The ash is highly abrasive and because of the high ash content of the fuel, the inlet dust burden is very high (100 g/m³) (11). Mechanical collectors are installed ahead of electrostatic precipitators for collecting the ash. The ash from some furnaces is well fused, forming cenospheres. In other instances, the particles are mostly crystalline and irregular in shape, with no evidence of fusion. The combustible content of the ash is 0-20%. The chemical composition of fly ash from Kansk-Achinsk coal is reported (144).

The problem of abrasion by fly ash is considered (145-148). The distribution of adherent particles with respect to adhesion forces is discussed (149).

The combustion of Ekibastuz coal presents problems due to the high mineral content of the coal, the high silica content of the ash, and the high temperatures required for satisfactory combustion in pulverized fuel fired furnaces (3,5,150,151). The abrasivity of the fly ash depends on the combustion temperature, reaching a maximum at 155°C in laboratory measurements.

Some physico-mechanical characteristics of ash and slag from thermal power plants are presented (152,153). The variation of free calcium oxide in fly ash from Nazarovo coal is discussed (154).

The effect of sulfur oxides in the flue gas on the caking capacity of fly ash was studied. With increasing content of sulfur oxides in flue gas, there was a considerable increase in the hardness of fly ash deposits (155). The effect of gas humidity in increasing the collection efficiency of an industrial dust is discussed (156).

Conditioning agents investigated for metallurgical dusts include: acetic acid (157), ammonium sulfate (158), and ammonium chloride (159); the use of naphthenate soap is patented (160).

The efficiency in collecting high-resistivity fly ash from the combustion of Ekibastuz coal decreased at temperatures above 120 C, but conditioning the flue gas with ammonia was effective in restoring the efficiency. The optimum level of ammonia addition was 25 ppm. The conditioning effect was reflected in changes in the electrical parameters of the precipitator, in the decrease of the electrical resistivity of fly ash to 6 x 10^{9} ohm-cm, and in the increase in collection efficiency from 88.5 to 98.3% (3,9,161,162).

A report published later concludes that ammonia is not effective enough to justify its cost and the logistical problems involved in its use. The flue gas can be sufficiently conditioned by a wet scrubber installed upstream of the precipitator. Either a centrifugal scrubber or a venturi followed by a mist eliminator can be used (3).

ELECTRICAL ENERGIZATION

The electrical stability of discharge gaps as related to the problem of an impulse power supply to an electrostatic precipitator is discussed (163). New electric sets for electrostatic precipitators are described (164). The use of thymistors for circuit control is discussed (165). Increasing the effectiveness of the high-voltage supply on electrostatic precipitators is discussed (166,167). Protecting high-voltage cables on precipitators from sparking is discussed (168). Horizontal multifield electrostatic precipitators with electrodes 12 m high, a 16 m length of active zone, and an active cross-section of up to 265 m^{2} are being installed on power units of 300 MW or more. This geometry is causing problems such as reentrainment of fly ash (6,169).

RAPPING AND FLY ASH REENTRAINMENT

Optimum rapping regimes in collecting fly ash (170-174) and their relation to reentrainment of fly ash have been studied (175-177). The optimum rapping interval with a constant thickness of dust layer being deposited in various fields of the precipitator is related to: the interval between raps in the first field, the same for subsequent fields, the effective migration velocity of particles in the corresponding fields, and the specific collecting surface areas in the corresponding fields (173).

The effectiveness of removing dust deposited on a collection electrode was found to depend on the direction of the rapping impact, the type of electrode and the mechanical stability of the deposited layer, its porosity, and its total mass (178).

A graphical method for optimizing the rapping regime has been developed. An integral curve was constructed for evaluating the degree of rapping a 12 m collection electrode. The curve gives the relative surface area on which dust is deposited for a corresponding value of rapping acceleration, independent of the physico-chemical properties of the dust (179).

Experiments with various rapping intervals, to determine optimum rapping cycles, have resulted in reduction in emissions by 25 to 40%. To ensure the required schedule for rapping the collection electrodes, special devices have been developed - variators with adjustment of the gear ratio from 1:8 to 1:72, which avoid the complication of the commutation system and facilitate the operation of the drives and mechanisms. The variators have high operating reliability (11,175).

Suppression of dust carryover by strong electric fields is described (180).

GAS FLOW

Studies have been carried out over several years on the effects of non-uniformity of gas flow on the efficiency of precipitators in collecting dusts, mostly fly ash. Studies of fly ash concentrations in the vertical plane of a precipitator outlet have shown higher concentrations of fly ash near the bottom in the lower part of the equipment. The design of inlet and outlet sections of the precipitator and of baffles to achieve uniform gas flow has been experimentally investigated by means of aerodynamic models (122,181-187).

The problems in the uniformity of gas flow presented by the use of high (10-12 m) electrodes in new precipitators installed in power plants have been studied and designs for diffuser grids suggested (188,189).

Some of the changes in precipitator design also reduce the reentrainment of agglomerated fly ash from the collection electrode (11,19).

Correcting an uneven gas flow by incorporating air distribution plates into an electrostatic precipitator installed at a cement plant increased its collection efficiency from 98.4% to 98.8-99.2% (190).

Electrostatic precipitators with flow of the dust-laden gas transverse to the electrodes were efficient in the collection of high-resistivity dust, e.g., lead smelter fumes from a sintering plant (191).

A coefficient of non-uniformity was introduced into the Deutsch equation. The predicted dependence of collection efficiency on this coefficient was verified by tests on a full-scale precipitator in a power station (192).

The effect of turbulence in the gas stream on the deposition of aerosol particles in a tubular precipitator has been studied with a computerized mathematical model (193,194).

One simplified model that has been suggested for the study of turbulent diffusion of particles suspended in a linear gas flow assumes constant gas flow and neglects factors such as molecular particle diffusion, turbulent particle diffusion along the flow direction, and inertial effects (195).

The mechanics of removing fly ash from precipitator hoppers and transporting it by wet and dry processes are discussed (196-202).

A system of ash removal with the aid of an air duct is described. It is used for handling ash from combustion of a mixture of Kansk-Achinsk and Borodino coals. The ash has cementing properties (203).

The effect of initial ash deposits on high temperature corrosion of boiler steel was studied (204). An internal structure designed to reduce corrosion was patented (205).

Procedures for installation, maintenance, and testing of electrostatic precipitators in electric power plants have been published (206,207).

Industrial uses of fly ash are described (208,209).

WET ELECTROSTATIC PRECIPITATORS

Tests on a 3-field tubular wet electrostatic precipitator of industrial size showed it to be effective in collecting hazardous silica dust (210).

A process for wet dust collection is based on preliminary charging of aerosol particles (sodium silicofluoride dust). The collection efficiency and the relation of particle charge to dust loading and corona potential were studied (211).

A method for preliminary charging of an aerosol by corona and collection on a liquid film or foam is described (212).

A wet electrostatic precipitator was more effective than a turbulent scrubber or a dry glass fiber filter in collecting an ionizable additive in an experimental magnetohydrodynamic apparatus (213,214).

A patent describes a process of cleaning a gas of dust by passing it through a liquid on which is imposed an electric field of 30-200 A/m^2 (215).

INDUSTRIAL APPLICATIONS

Electrostatic precipitators and scrubbers are recommended for removing dust and hydrogen fluoride in cleaning gases from aluminum cells (216). The condensation of tarry products from the gas in the precipitator was investigated (217). The performance of a two-stage system was studied (218).

Discussions of the use of electrostatic precipitators in nonferrous metallurgical operations include a review on research in the U.S.S.R. on the subject (219) and accounts of specific applications: mercury production (142,220,221); copper production (222-224), roasting of copper and zinc ores and pyrites (225,226), and arsenic recovery (227,228).

A study of the electrostatic precipitator in collecting the fumes in process gases at high temperatures at a tin smelter showed that an increase in the temperature of collection did not decrease the collection efficiency, but decreased the content of arsenic in the sublimate and the amount of water vapor in the gas phase. As a result the working life of the precipitator was increased (229).

Applications in the iron and steel industry are discussed in general (230-235).

Electrostatic precipitators with needle discharge electrodes and C-shaped collecting electrodes, with three fields, effective cross-section 70 m^2, were installed on a 400-ton open-hearth furnace, with oxygen lancing (236).

In studies of factors affecting performance of precipitators installed on open-hearth furnaces, precipitators were satisfactorily operated on open-hearth furnaces without oxygen lancing, but with it humidifying the gas was required (237-239).

The performance of combined wet scrubbers and electrostatic precipitators in tandem on an open-hearth furnace is described (240,241).

Electrostatic precipitators used to recover iron ore fumes from roasting machines had designs based on needle corona electrodes and C-shaped collection electrodes (142).

Other industrial applications for electrostatic precipitators include: the cleaning of coke oven gases (243), mist recovery in sulfuric acid manufacturing (needle corona electrodes are used) (227,244,245); cleaning gases in high-resistivity magnesite dust (246-249); cleaning gases in the production of carbon black (250,251); cleaning of kiln gas in cement manufacturing (190), including a discussion of some operating problems (252); dust removal in the manufacture of fire brick (253) and from gases emitted from rotary kilns for baking clay (254); cleaning gases from kilns for electrode production (255); and cleaning gases from burning dolomite (256).

SECTION 3

WET SCRUBBERS

USE IN ELECTRIC POWER PLANTS

Wet dust collectors with venturi coagulators installed on power units with a capacity of up to 300 MW are widely employed at electric power plants of the U.S.S.R. (257). These devices collect 95-97% of the ash from flue gases with a total specific consumption of water of up to 0.25 l/m³ and hydraulic resistance of 80-120 kg/m². The flue gases are cooled in the collectors to 50-70°C and on emission have a temperature approximately 20°C higher than the wet-bulb temperature thermometer. This condition is used to prevent corrosion of the ducts and stacks, since the gases are not re-heated following the collector.

Attempts to improve the design of the collector led to the development of wet, high-speed ash collectors. The basic feature of these collectors is the shortening, in comparison with the normal design, of the intake duct, which is a venturi coagulator with a rectangular cross section which immediately adjoins the housing of the apparatus without any intermediate sections. The relatively large apex angles of the diffusor and convergent channel of the coagulator permit reducing its length in comparison with regular design, thereby providing normal irrigation of the coagulator walls over their entire length and preventing the formation of deposits on poorly moistened sections of the walls.

Placed in front of the coagulator of the apparatus in a small section for acceleration of large fly ash particles to velocities of at least 15 m/sec, which enhances somewhat their capture by drops of water in the coagulator but more important, provides an intensive abrasion, by the coarse ash particles, of the deposits which form at the boundaries of the dry and irrigated portions of the walls of the convergent channel. The stabilization of the dimensions of the boundary deposits attained here prevents the increase in the hydraulic resistance of the ash collector caused by the growth of these deposits (147,199,257-260).

In the 1950's and 1960's, centrifugal scrubbers were widely used in electric power plants of the U.S.S.R. for cleaning flue

gases. In recent years, these devices have been improved by redesigning the intake duct to a venturi type. As a result, the efficiency of collecting the fly ash increased to 97-98%. However, despite such high efficiencies, wet scrubbers are used only on units with capacities of less than 200 MW. This limitation is connected with the inevitable cooling of the flue gas in the scrubber and the corresponding poorer dissipation in the atmosphere of the gases emitted from the stack. Work on the improvement of wet ash collectors is at present being conducted in the direction of further increases in effectiveness and on the possibility of spraying with water in closed loop ash-removal systems (259,261).

As the practice of operating ash collectors with venturi coagulator tubes for many years shows, they are very reliable and effective devices with a high collection efficiency, 96.5-97%, which is sufficient in many installations (262).

At the same time, the increased requirements for protection of the atmosphere and the growth in capacities of boiler units and electric power plants in general urgently require a further reduction in the fly ash content of the effluent gases and the attainment of a collection efficiency of 99% for electric power plants of medium size equipped with boiler units of up to 650 tons of steam per hour.

To explore the possibilities of increasing the collection efficiency of these devices, the effect of various parameters on the process of capture of ash particles by drops of atomized liquid in venturi tubes was analyzed, and a mathematical model of the process was developed taking into account the continuous change in the velocity of the fly ash particles and water droplets in the venturi and with consideration of the transformation of the polydisperse distribution of the fly ash particles and water drops according to size (262).

An increase in the particle residence time in the venturi, i.e., an increase in the length of the tube, has a positive effect. The rates of gas flow in the throat which are used in practice, on the order of 60 m/sec, are optimum for larger particles.

The consumption of atomized water on the order of 0.12-0.14 l/m^3(NTP) which is at present used is also optimum in the sense that increasing it substantially increases the cost of scrubbing and increases only insignificantly the collection efficiency.

A change in the size of the water droplets affects the degree of collection noticeably. At the same time, a reduction in the droplet size, for the same amount of consumption of

water, although it reduces the collection of particles on an individual droplet, as a consequence of the sharp increase in the number of droplets leads to a noticeable increase in collection.

The best approach to an intensification of the capture of particles by droplets in the venturi is an increase in the fineness of atomization of the water. Full-scale tests of this conclusion were conducted which confirm its validity (262,263).

MECHANISMS OF ACTION

Several theoretical papers on diffusiophoresis and thermophoresis and their roles in scrubber action have been published. Expressions have been derived for the rates of diffusiophoresis and Stefan flow of small volatile aerosol particles in a binary gas mixture in which one component is the same substance as that of the particles (e.g., water droplets in wet air) (264). The rates of diffusiophoresis of large non-volatile aerosol particles (265) and volatile particles of medium size were studied (266). During vaporization of a drop, the velocity of the possible hydrodynamic flow (Stefan flow) is of the size of terms that can be neglected (267). Efficiency of collection of aerosol particles by Stefan flow was analysed (268).

The theory of thermophoresis of volatile aerosol particles and its relation to the Knudsen number are discussed (269-274). The role of thermophoresis and diffusiophoresis processes in cloud formation are discussed (275). These forces are negligible in aerosol sedimentation (276). Photophoresis can also be involved (277).

The theory of thermophoresis and diffusiophoresis is discussed in terms of equations accounting for isothermal, thermal, and diffusion flow (278).

Equations for the thermodiffusiophoretic forces and the drag forces of the medium have been derived that take into account the volatility of the collecting drops. The effect of the volatility is proportional to the ratio of the radius of the drop to the mean free path in the supporting gas, but is generally less than 1% (274).

In a system containing large spherical drops, solid particles, and gas bubbles, hydrodynamic theory shows that a general formula for the rate of thermophoresis contains two terms. The first is proportional to the coefficient of thermal slippage of the surface of the particle, and the second is the derivative of the surface tension relative to temperature (279).

An equation was obtained for the rate and intensity of thermodiffusiophoresis in a multi-component gas. The equation includes allowances for dynamic viscosity, particle radius, diffusion slip of the gases, thermal conductivity of the gases and particles, mean free path of the gas molecules, density of the components, and gas temperature (280).

Aerosol deposition mechanisms occurring in water vapor diffusion fields were studied in a vertical plane-parallel channel in which dusty, vapor-supersaturated air was cooled. Aerosol sedimentation in water vapor diffusion fields is primarily due to diffusive forces. The contributions of thermodiffusion and diffusiophoresis to sedimentation are negligible (276). A mathematical model for the formation of aerosol particles by condensation of supersaturated vapor was prepared (281).

Experiments were conducted on the deposition of molecules on spherical aerosol particles (282). Experimental observations showed that fluctuations in temperature, pressure, and humidity favor the formation of large droplets by condensation (283). Aerosol particle motion and capture with relation to growing or evaporating drops was studied (272,284). Trajectories of volatile aerosol particles were studied (285).

Condensation in venturis was found to be effective in removing hydrophobic particles (286-290). Condensation of a dense vapor flow was investigated (291).

The kinetics of diffusive growth of particles were measured (292-294). The role of molecular forces in the coagulation of liquid aerosol particles is not large (295). The dependence of molecular forces on particle size was studied (296).

Improved collection efficiency resulted from preliminary electrification of the aerosol collected by wet scrubbing (297); this was observed especially for the finer fractions of the aerosol. The effect was found in the collection of sodium fluosilicate aerosol in a laboratory foam scrubber. The growth rate of drops in an electric field was 2.5-fold higher than without the field (298). The deposition of dust particles on droplets from ultrasonic atomization was investigated (299).

TYPES OF SCRUBBERS

A survey of scrubbers available for removing dust from gases was made (300), factors involved in selecting a scrubber are discussed (301), and prices are given for installed scrubbers (302).

For dust collection in sieve-plate or packed spray columns, information has been published on pressure drop (303-305), critical parameters and calculations of foaming conditions (306-308),

hydraulic resistance (309-312), liquid entrainment (313,314) and collection efficiency (315).

For collection of fly ash and other industrial particulate matter in venturi scrubbers, information has been published on: component equipment for power plants (261); calculation of collection efficiency for soot (316); droplet size distribution for fly ash collection (317); use of wetting agents in collecting fly ash (318); calculation of collection efficiency (319); derivation of formulas for fractional collection efficiency which take into consideration the size distribution of the droplets (320); use of design factors in investigating scrubber processes (321); comparison of ejection-type venturi scrubbers with the usual venturi (322); type of atomiser (323); experimental determination of the effect of the extent of atomisation of the water in the action of venturi fly ash collectors up to 25 kg/cm^3 (324); selection of optimal parameters of venturi tubes for cleaning gases from open-hearth furnaces and converters (325,326) and in lime regenerating kilns (327); the need for using a droplet size distribution in the design of a venturi (328); the use of a 10^4m^3/hr pilot-scale venturi scrubber for evaluating performance parameters (329).

In a study of the hydraulic resistance of a venturi tube with an irrigated diffuser, the location of spray nozzles for uniform irrigation was determined (323,330,331). An empirical relation of the coefficient of hydraulic resistance to operating parameters was obtained (332). The effects of particle aggregation (333) and viscosity of the liquid (334) were noted.

The degree of dispersion of water droplets at different gas velocities, throughputs, and atomiser locations in the throat of a venturi scrubber was measured by light scattering (335). A similar study allowed a rational choice of droplet size to be made (336). Another defined the upper limit on two-phase flow (337).

On the basis of a study of liquid dispersion, the theory of coagulation, and data on hydraulic resistance, a system of equations was obtained for aid in selecting equipment (338).

Heat transfer processes in venturi and packed scrubbers were studied (339-341).

The chemical and mineralogical compositions of deposits formed in a spray grid-packed scrubber in a power plant were about the same as those for the fly ash (342).

The collection efficiency for fly ash was measured and calculated for a centrifugal scrubber (343). A conical scrubber with a fluidised bed of spherical packing was designed (344), and one with coaxial tubes (345).

The performance of a wet dust collector with a disk liquid atomiser was examined and a statistical model suggested (346).

The efficiency of a scrubber collecting by impaction was measured (347).

A foam-vortex scrubber was designed and tested as a dust collector and gas absorber (348).

The collection efficiencies of various scrubber designs were measured (349).

A high-capacity, high-efficiency vortex type absorber for gas absorption and particulate retention from industrial waste gases is described. The turbulent motion of tangentially admitted gas streams is increased by the vortex generator, whereby the wash liquid admitted into the contact zone is disintegrated to droplets (350).

A method for the determination of statistical characteristics of the motion of suspended particles in a turbulent flow was developed. Previously derived differential equations describing the motion of solid suspended particles in a fluid pulsating stream were used, specifically in the case of slowly pulsating turbulent flows of low Reynolds numbers of 1-10. The moments of the first two orders of a random function were obtained, which characterise the velocity of the suspended particle (351).

INDUSTRIAL APPLICATIONS

Scrubber applications in the iron and steel industry are described (352); installations on cupolas are discussed (353).

The performance of a scrubber-electrostatic precipitator combination was analysed as a function of gas temperature, velocity, and the number of electrical sets in the precipitator (354). It was shown that preliminary cooling of the open-hearth gases prior to venturi scrubbers was of no advantage (355). The performance of venturi scrubbers on open-hearth furnaces was studied (356-358).

Studies of design and operating parameters in applying scrubbers to gases from electric steel furnaces are described (352,359-367).

The use of scrubbers on oxygen converters is described (368,369). They are compared with electrostatic precipitators on converters (370) and ore dressing plants (371). Their use on sintering machines is noted (372,373).

Heat transfer calculations are given for scrubbers under pressure on blast furnaces (374).

Applications for cleaning gases in the aluminum industry have been discussed in a number of articles (375-377); the design of a grating-type scrubber (378); the redesign of a vertical-louver scrubber to reduce deposits on the louvers (379); the composition of alkaline scrubbing liquids (380); determining the extent of drop entrainment (381); the use of a scrubber with suspended spherical packing (382); a comparison of types of scrubbers, which indicated that the rate of dust removal was highest for fluidised bed scrubbers and lowest for foam scrubbers (383); studies of the design and operating parameters for spray chambers (384,385); a comparison of scrubbers with electrostatic precipitators (216); and the use of surface-active agents (386).

Scrubbers are also used for cleaning stack gases in sulfuric acid manufacture (387), and in carbon black production (251). A moving bed scrubber is used for collection of sodium fluoride dust (388).

The cleaning of roaster gas containing 5 g/m³ of arsenic was studied with a dry electrostatic precipitator, a packed scrubber, and a wet electrostatic precipitator in series (228) and with a venturi scrubber (389). Scrubbers on copper smelters are described (390).

Other applications include the use of a high-efficiency scrubber in aluminosilicate roasting ovens (391); scrubbers containing a moving bed of plastic spheres plus a cyclone in silicate production (392), and the recovery of an ionizable additive in an experimental magnetohydrodynamic apparatus (213,214).

SECTION 4

FABRIC FILTERS

Fabric filters (baghouses) are apparently not installed on electric power boilers in the U.S.S.R. They are widely used for the control of other industrial sources of particulate emissions, such as metallurgical operations.

A large body of information is published in the U.S.S.R. on the theory and mechanisms of collection of particles in fibrous filters. Also the design of baghouses and the selection and use of filter fabrics are well covered in the Russian literature. Some of the more recent information on these topics is included (393).

COLLECTION MECHANISMS

The theory of filtration is described (394). The upper and lower limits of aerosol penetration through a fibrous filter at Peclet numbers <1 were estimated theoretically by assuming a haphazardly interwoven network with the axes of fibers parallel to the plane of flow (395).

A new filtration theory based on the inertial theory of deposition but including coulombic forces acting in the collection of particles is presented (396).

An experimental and theoretical study was made of the action of a fibrous filter collecting particles by diffusion (397). The dependence of pressure drop across a filter on the Knudsen number was studied experimentally and theoretically for a simple model of parallel cylinders perpendicular to the gas flow (398-400). Calculated and measured penetrations were obtained for filters made of fibers <1 ppm in diameter (401). The behavior of suspended particles near hard walls was studied (402,403).

A theoretical equation for the separation of aerosols by a cylindrical filter was developed (404). Equations are presented for describing one-dimensional non-stationary gas filtration in porous media (405).

The cleaning process in bag filters was studied with the aid of beta radiation attenuation of the deposited dust layers (406,407).

Equations were obtained that relate performance to filter parameters (408).

The flux of gas molecules toward a suspended particle was calculated; comparison with experiment was hindered by the lack of data (282). The statistical characteristics of the motion of suspended particles as related to the gas flow were studied (351).

The aerodynamics of dust-removal apparatus are discussed (409). The hydraulic characteristics of filter materials were investigated (410). The determination of the mean radius of filter fibers is reported (411).

A simplified model was used for the study of turbulent diffusion of particles suspended in a flowing gas (195). Theory was developed for the settling of aerosol particles from turbulent gas flow and it was shown that the mechanism and velocity of turbulent inertial settling of aerosols is governed by the effect of the transverse migration of particles to the walls (412,413).

A process is described in which gases are filtered with prior electrical charging of the dust particles, with periodic charging of the filter with the same sign for regeneration (414).

Calculations were made to show that the efficiency of a self-cleaning filter depends on the fiber length (415). Investigation of the empirical relationship of capture coefficient to the packing density of a filter showed that with an increase in packing density the deposition increases as the result of particle inertia and capture (416).

The effect of ultrasound on filtration by small capillary filters was reported (417). The flow of air through a porous metal barrier was studied (418), as well as the two-dimensional flow of dust-laden gas through a nozzle (419). Capture coefficients were calculated for spheres at high Reynolds numbers (420). Capture coefficients by star-shaped collectors were measured (421).

Methods were developed for estimating the extent of filling of pores of different sizes, for relation to filter performance (422).

A study was made of the volume and surface characteristics of lubricants defining the film thickness of panels of self-cleaning filters (423).

An investigation showed that the hydrodynamic resistance of a layer of mixed fibers is less than the sum of the resistances of equivalent layers of uniform fibers (424). Multilayer fiber filters were studied (425).

A method was developed for calculating the capture coefficient based on diffusion and entanglement of particles, including an allowance for gas slippage around the fibers, the polydispersity of the fibers, and the non-uniformity of filter structure (426).

BAGHOUSES

A bag filter holder was designed with separate chambers for dusty and cleaned gas (427). Mechanical structures for improved regeneration of bag filters are described (428,429).

On the basis of experimental data on the dust distribution in a bag, an empirical equation was obtained from which the geometrical parameters of the bag can be evaluated in dependence on the gas flow rate (430).

Twisting a bag filter was found to be superior to reverse jet cleaning for increasing the filter action without increasing the filter resistance (431). Regeneration by fabric deformation (432) and mechanical shaking with an electric vibrator (433), reverse jet (434), and pulsation (435) are described.

Various bag constructions are given: a truncated cone (436), centrifugal regeneration (437), improved support structures (438).

A technical-economic evaluation was made of fabric filter installations handling 100,000 m^3/hr gas flow with different methods of regeneration (439).

Studies were made of regeneration, by vacuum and ultrasonic processes, of non-woven fabrics made from synthetic fibers (440), and a method for regeneration was patented (441).

Correlations were made of the structure and properties of filter fabrics with the basic indexes of filtration of dust-laden gases (442).

The relationship of air flow resistance to time and the breakthrough of a filter were measured (443). The mechanisms of deposition of particles on a metalloceramic metallurgical filter were investigated (444).

A survey of applications and methods of regeneration was recently published (445).

FILTER FABRICS

A standard aerosol was used to determine the filtration properties of synthetic fabrics (446). Quartz dust was used for a similar study (447).

Information on various glass fiber fabrics is presented (448). The tensile strength of glass fiber was maximum at 80-100°C but depended on the absolute humidity of the air (449). The durability of glass fibers in filters is maximum at some temperature below 200°C (450). The physical properties of glass-fiber filters containing organic phosphates were determined (451).

Metal-ceramic fibers for metallurgical filters are described (452), as are metal fabrics (453, 454) and ceramic filters for recovery of carbon black (455).

Fabrics made of metallic fibers were found to be suitable for use in collecting dust from blast furnace gas and electric furnaces and in ore-dressing plants. After a precoat layer was formed on a fabric with a linear pore size of about 100 μm, the gas was filtered at 25 m^3/min at 700-800°C (456). New polyamide fibers appear to have greater thermomechanical stability than glass fibers (up to 300°C) (393,457).

Titanium dioxide was recovered from flue gas by a metal ceramic filter made by sintering a 0.1 mm steel powder (458).

A separator constructed of porous sintered nickel-copper tubes used for collecting metallurgical dusts is patented. It is regenerated by reverse air flow (459).

Fibers made of ion-exchange materials were used for separation of liquid aerosol materials in the cleaning of galvanising equipment emissions (460).

MIST ELIMINATORS

The development of high-velocity (gas volumes up to 30,000 m^3/hr) mist eliminators is described (461). Glass fibers or synthetic fibers are used. The mechanism of action, including liquid droplet collection and migration, has been studied (461-464). Louver-type designs have been investigated (465,466).

A column containing perforated caps covered by filtering material was patented (467), and a cartridge design containing glass fibers (1.5 μm in diameter) was described (468). The optimum structure of polypropylene fiber felts for acid droplet collection was found to be based on a fiber diameter of 15-20 μm (469,470). The collection efficiency of a 3 μm-diameter filament vibrated by sound was determined (471).

INDUSTRIAL APPLICATIONS

Applications of fabric filters include their use for collecting metallurgical fumes from open-hearth furnaces before passage through waste-heat boilers (472), oxygen converters (370), and electric furnaces (473). A rotary dust collector made with a metallic fabric, tested in a sintering plant, showed 87-90% collection efficiency (474).

The use of fabric filters in non-ferrous metallurgy includes ore smelters (220,475-481). They are also used in the production of carbon black (482,483), titanium dioxide (484), and cement (485).

Bag filters of synthetic fiber fabrics were superior to high-pressure venturi scrubbers for removing dust from gas from a silicon smeltering furnace (486).

SECTION 5

OTHER COLLECTORS

CYCLONES

Cyclones and similar mechanical collectors for gas cleaning are discussed in several articles (485,487-501).

Applications that are considered include electric power plants (495,501-506), open-hearth furnaces (507), coke ovens (508), chemical plants (509), and catalyst beds (510,511).

Experimental designs and studies of gas flow in cyclones are presented (500,501,512-521) and methods for analysing and improving their operation are suggested (522-530).

For cleaning flue gases at electric power plants, batteries of cyclones with collection efficiencies of 94-95% are used. The use of these devices is limited to units with boiler ratings of up to 420 tons/hr burning low-ash fuels such as peat (531) and coal from the Kansk-Achinsk deposit (6).

GRANULAR BED FILTERS

The use of granular bed filters for recovering carbon black from combustion gases at 600 C is described (532); designs have been patented (533). The use of electrically charged granules was patented (534). Applications for granular bed filters include metallurgy (535), cement manufacturing (536), and the collection of silica particles (537).

A high-gradient magnetic filter with a bed of 8-mm steel balls was tested for the removal of dust (60 m^3/min) from a 900-ton open-hearth furnace. At the optimum voltage of 80-120 kA/m, the collection efficiency was 80-90%, and the energy consumption was 0.05 kWh/1000 m^3 of gas. Without the magnetic field the collection efficiency was 35-30% (538).

ACOUSTICAL PROCESSES IN PARTICLE COLLECTION

Several investigations have been reported on the acoustic coagulation of aerosols. The designs and mechanisms of acoustic generators are described (539-541). Their possible use in power plants for cleaning stack gases is considered (542). Acoustic

coagulation of shale dust is described (543). A gas-jet acoustic generator was effective in coagulation of carbon black particles (544). The rate of coagulation of an aerosol in an acoustic field was measured as a function of particle size and other parameters (545). The variation in mobility of small particles in an acoustic field causes a sizable deviation in diffusivity (546).

SECTION 6

SAMPLING AND MEASUREMENT METHODS

Studies of impactors include their use in sampling dust from aluminum pot lines and measuring its electrical resistivity (151) and in sampling sulfuric acid mist (547). Work on impactors has also included their use in sampling gases with dust loadings of 5-7 g/m³ at 100°C (548), and studies of their accuracy (549), efficiency (550), and calibration (551). Designs were developed for multi-stage impactors (552,553). A grease for retaining deposited particles is patented (554).

Information has been published on filters for sampling dust emissions from aluminum pot lines (555) and on metal fiber filters for sampling hot gases (556,557). Compact automatic sampling devices, in which aerosol particles are captured by a fiber filter, have been developed (558-561).

Techniques and apparatus for sampling hot and corrosive gases (562) and for maintaining isokinetic sampling are described (563,564). A tape feed mechanism was developed for aerosol sampling (565). An electrostatic precipitator for sampling dust is described (566). A probe connected to a thimble filter and a capacitor were developed for measuring the charge on aerosol particles in gas streams (567).

Various techniques for determining particle size distribution of particulate matter are described (553,568-575). In one type of analyzer, a rotary centrifuge draws the dust-laden gas through a channel in the rotor and the particles are separated by centrifugal force (576). Flue gas probes for determining particle size distribution have been used (577, 578). A thermal coagulation technique for determining particle size distribution was developed (579). Techniques for measuring particle trajectories are discussed (580).

Methods and apparatus for generating sodium chloride aerosols are described (581). The production of model aerosols from solution is discussed (582). A model developed for calculating the particle-size distribution of coagulated aerosols gives a nearly log-normal distribution (583).

Techniques for studying the microphysical characteristics of liquid aerosols in industrial emissions are discussed (584).

The determination of the angle of repose of dust is described (585) as well as its cohesion (586,587) and wettability (588).

A list of basic equipment used in dust and gas research is given (589). Techniques for determining the dust loading of flue gases (590-592) and the concentration and properties of dusts are described (593).

A method of measuring dust loadings in flue gas in the stack is based on deposition of an electric charge by the impact of the dust particles in an air jet (594).

A differential thermal method (595) and a capacitance method (596) for determining the concentration of combustible matter in fly ash were developed.

The determination of gas humidity (597), dew point (598), and true density of dust (599) are described.

The measurement of electrical resistivity of fly ash is discussed in Section 2 of the report.

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